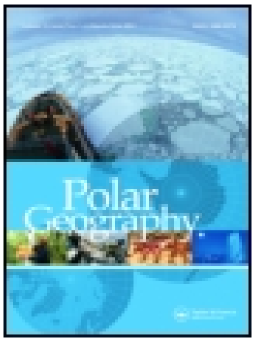

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Mapping weather, water, ice and climate (WWIC) information providers in Polar Regions: who are they and who do they serve?

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ABSTRACT

Environmental conditions in Polar Regions are becoming more dynamic due to climate change. As sea ice melts, the range of human activities in Polar Regions are projected to increase, while weather conditions are becoming more extreme and unpredictable. Provision and use of weather, water, ice and climate (WWIC) information plays a key role in ensuring that polar activities are conducted as safely as possible and can contribute to a reduction of the environmental footprint of human activities. In this article, we explore the WWIC information provider landscape in a polar context, drawing on a database we compiled to characterize the diversity of providers. The database is built on available literature and on an extensive desk-based research of WWIC information provider websites. We analyse the 374 providers categorized by (a) institutional background (public vs private), (b) the position of the provider relative to activities in the WWIC information space, and (c) the users they serve. While governmental institutions have a strong presence in information provision, new types of providers are now entering the scene. Scientific actors seem to play a substantial role as users as well as major providers of WWIC information services.

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Introduction

The Polar Regions include the most rapidly and profoundly changing areas of the planet (Larsen et al., 2014; Vaughan et al., 2013). While communities, governments and economic sectors face challenges in adapting to these impacts, there are also underlying opportunities (Larsen et al., 2014). For example, current and projected climatic changes in the Arctic and parts of the Antarctic, particularly changes in sea ice cover, are expected to enable an increase in marine activities, such as shipping, tourism and fisheries, as well as in maritime services, such as port development (Arctic Council, 2009; Larsen et al., 2014; Rintoul et al., 2018). Simultaneously, climate change is believed to increase hazards related to the

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thawing of permafrost, the increased frequency and intensity of extreme weather events (e.g. winds, waves, icing) and the increasing variability of sea-ice drift (Lamers & Amelung, 2010; Larsen et al., 2014; Stewart, Dawson, & Johnston, 2015). Variability across various time scales (e.g. decadal, annual, sub-seasonal) increases uncertainty in decision-making for diverse actors. These actors include individuals and organizations in community, public and private sectors making decisions related to all aspects of human activity, including mobility, dwelling and economic investments (Arctic Council, 2009; Dawson et al., 2017).

Weather, water, ice and climate (WWIC) information ranges from instrumental monitoring and observation data of the historical and current state of the environment, to forecasts of future environmental conditions at a range of timescales. WWIC information services vary from information publicly broadcasted to tailored services for specific user needs. WWIC information plays a key role in managing the risks posed by climate change and harnessing the potential benefits that climate change may bring, especially for the Arctic. Provision and use of timely and accurate WWIC information can contribute to increased safety and efficiency in polar activities. When utilized in planning and decision-making, WWIC information can contribute to the viable development of activities and can help actors to adapt to changing conditions. The usability of information depends on fit, interplay and interaction between the information provider and the user. One challenge in making climate information usable is a mismatch between providers and the growing scale and dynamic nature of user communities and needs (Lemos, Kirchhoff, & Ramprasad, 2012). As the demand for information increases, providers might not be able to keep up with establishing interactive relationships with the users, which are often critical to increase usability (Lemos et al., 2012). Thus, there needs to be more effective engagement between the user and provider (Hewitt, Stone, & Tait, 2017). In addition, there are also issues of temporal and spatial scale in which the WWIC information is provided in Polar Regions (Dawson et al., 2017). These scales are often too coarse to inform local decisions. While usability of WWIC information is always context dependent, global frameworks, such as the Global Framework for Climate Services (GFCS), aim enable the management of risks and opportunities in different sectors by implementing coordination and promotion activities and projects (Hewitt, Mason, & Walland, 2012). User engagement in the GFCS happens on the User Interface Platform, which brings users, researchers and providers from different levels together to define user needs and provider capabilities, with the ultimate aim of promoting effective decision-making (WMO, 2014).

Over the last two decades, the worldwide provision of WWIC information services has changed due to three important societal drivers. First, climate change has brought meteorological research and services to the attention of the public, and adaptation challenges to climate change are generating a growing need for such services (Hewitt et al., 2012; IPCC, 1990; WMO, 2014). There is a growing awareness that adaptation challenges are faced by many community and economic sectors. For example, the immediate opportunities of WWIC information for harnessing the benefits for human safety and well-being prevail in agriculture and food security, disaster risk reduction, health and water resources (Hewitt et al., 2012).

Second, the historic commercialization and neoliberal privatization of meteorology has hollowed out public services and pushed service delivery toward the private sector with important consequences for end users (Randalls, 2010). From an institutional perspective, the provision of meteorological information services has shifted from being dominated by public organizations to a world where private sector actors and organizations are more prominent in the service-production chain and where the users WWIC information services are becoming paying customers. For example, in the European context, the commercial provision of weather services began in the 1970s with the growth of hydrocarbon exploration, when companies started indicating that they were willing to pay for meteorological services (Pettifer, 2015).

Third, the emergence of the Internet, and particularly the development of Web2.0 over the last 15 years, has changed the platforms used to access information. It has also enabled the creation of open-source online applications where user-generated content can be made available. Moreover, technological advancements in earth observation, supercomputing and mobile communication technology have contributed to the enhanced availability and accessibility of WWIC services, ranging from real-time information, to sub-seasonal and seasonal forecasts.

As a consequence of these three societal drivers, worldwide WWIC services provision is becoming increasingly targeted and tailored to the needs of specific user groups. In other words, WWIC information provision is increasingly shifting from supply-driven to demand-driven services.

How these drivers are affecting WWIC services provision in the Polar Regions is not well understood. Better understanding of WWIC service provision is needed due to the rapid and ongoing environmental changes and growing information needs of communities and economic sectors in these regions. To begin to address this knowledge gap, we developed a database (inventory) of WWIC providers and analysed their institutional status, activity types and target users. The aim of this paper is to characterize the 'provider-scape' of WWIC services in Polar Regions. This is a necessary step in understanding the scope and focus of WWIC information provision and identifying any obstacles to salient service delivery. While the focus of this article is on WWIC information provision, the user side is also discussed, as the distinction of information provider and user is rarely binary (Thoman Jr. et al., 2017).

WWIC service delivery in the Polar Regions

The provision of WWIC information requires a robust earth-system observation system that allows for the collection of meteorological, hydrologic, oceanographic, land-cover and climate data, as well as the capacity to process data, and the skills to turn processed data into usable products, such as public weather and climate forecasts and warnings. As the costs associated with constructing such an infrastructure are very high, most of the necessary functions for WWIC service delivery are typically represented, or contained within, public organizations, such as National Meteorological and Hydrological Services (NMHSs) (WMO, 2017a). As such, basic WWIC information is delivered as a public good, while more specialized services are typically distributed as a mix of public and private goods (Freebairn & Zillman, 2002). In the Polar Regions, NMHSs historically have a prominent role in observations and basic service delivery, but increased economic activities in the Polar Regions, particularly in the Arctic, have created a situation whereby specialized services are increasingly needed to ensure safe operations (Knol et al., 2018).

The ability to observe and predict WWIC conditions and phenomena in Polar Regions is limited due to a number of factors. The regions are large and unique in terms of weather patterns and trends; compared to the lower latitudes, human activity in the Polar Regions is generally less intensive or frequent; and the low population density has resulted in limited investment in meteorological infrastructure (Eicken, 2013; Inoue, Enomoto, & Hori, 2013; Jung et al., 2016; WMO, 2013). There has been reliance on global networks and other sources of information to collect the necessary observations for Polar Regions, for example initiatives by the World Meteorological Organization (WMO) (e.g. the Polar Space Task Group) and more organically formed working groups (e.g. the International Ice Charting Working Group). Even a primary WWIC information provider, such as an NMHS, is also a user of upstream data. Today, large international efforts attempt to improve observations, modeling and forecasting in Polar Regions, such as the WMO's Polar Prediction Project, the European Union's Earth Observation Program Copernicus or the INTAROS-project supporting the development of an integrated Arctic Observation System, as well as the Southern Ocean Observing System in the Antarctic (EU-INTAROS, 2017; European Union, 2015; Jung et al., 2016; SOOS, 2018; WMO, 2013). There is an Arctic Observation Assessment Framework aiming to support the evaluation of societal benefits accrued from Arctic observations (IDA Science and Technology Policy Institute and Sustaining Arctic Observing Networks, 2017). Furthermore, there is increasing expertise and an emerging body of literature on polar data management, related to different information resources, international collaboration and interoperability (Key et al., 2015; Parsons et al., 2011; Pulsifer et al., 2014).[1]

The infrastructural requirements and the objective of NMHSs on retaining their vital role in delivering earth observation services to their national audience in the future (Zillman, 2005) may explain why WWIC services have been developed traditionally in a provider-driven linear manner versus from user-driven needs. The linearity of the provision of WWIC information may also have roots in the notion of science coming first, and policy – and decision-making second, as suggested by Beck (2011). As the world becomes ever more interconnected, and as provider-user interactions intensify, the provision of WWIC information should be understood more as a web, or network, rather than a linear process because webbed and increasingly complex interactions may add important value to information provision (see also Dawson et al., 2017).

The current production of WWIC forecasts in the Polar Regions does not generally consider differences between user characteristics, as these differences are largely unknown (Thoman Jr. et al., 2017). At the same time, the user-scape is evolving. WWIC information is not provided only for explorative endeavors, such as research activities, resource explorations and adventure tourism (e.g. Lamers, Duske, & van Bets, 2018), but there are increasing efforts to support remote communities (e.g. Johnson et al., 2015). The needs of polar users regarding WWIC information have been discussed at a general level (Dawson et al., 2017; Duske, 2016; EC-PHORS, 2015; Gråbak, Arthurs, & Flemming, 2016), and to a lesser extent in more applied contexts, such as expedition cruising (e.g. Lamers et al., 2018), local communities (e.g. Alessa et al., 2016; Laidler et al., 2011) and shipping (Druckenmiller, Eicken, Johnson, Pringle, & Williams, 2009). Moreover, the future potential demand for polar WWIC services may vary depending on different future scenarios (Haavisto, Pilli-Sihvola, Harjanne, & Perrels, 2016).

Within the broader climate literature, improving scientific prediction and observation systems has received a great deal of attention, while the usability of the information has not (Kennel, Briggs, & Victor, 2016; Lemos et al., 2012). Also, in the Polar Regions, investments in observing and forecasting capabilities require major commitments (WMO, 2013), but attention is also increasingly necessary to accommodate user requirements and tailor WWIC services to specific uses during the Year of Polar Prediction (YOPP) (WMO, 2016).

Methodology

Following the idea of Vaughan, Dessai, and Hewitt (2018) and their investigation of climate services from a 'bird's-eye view' by reviewing self-reported climate services, we undertook a similar analysis with a focus on WWIC information provision in the Polar Regions. For the purpose of this paper, we define information providers as groups, organizations or enterprises that develop, hold, share, sell or exchange data, information and knowledge with the intention of influencing a belief, decision or behavior, or otherwise satisfying a real or perceived need of a given user in the Polar Regions. We define users as individuals or organizations engaging in polar activities, who receive, or are targeted to receive, WWIC information via providers. The paper builds on the work undertaken by the Polar Prediction Project's Societal and Economic Research and Applications task team (PPP-SERA[2]) (Dawson et al., 2017).

There are various ways to categorize providers and users of WWIC information in the Polar Regions; they may be distinguished by mandate or purpose, size and scope, activity, geographic coverage or focus, and longevity (Dawson et al., 2017). These characterizing features are specific to each organization and evoke a complete selection and categorization of provider and user organizations. It is often difficult to draw the line between the provider and user organizations: one may use information provided by the other and distribute it further in its existing, or in a different, form. To identify the main WWIC providers and users in Polar Regions, we undertook a thorough literature review and built an inventory of providers and users (see Figure 1). The literature review drew on a wide range of publications, including recent assessments by the EC-PHORS Services Task Team (2015) on polar service requirements, Duske et al.'s paper (2016) on Arctic geophysical information providers, Gråbak et al.'s discussion (2016) of user needs in relation to observation systems, a WMO

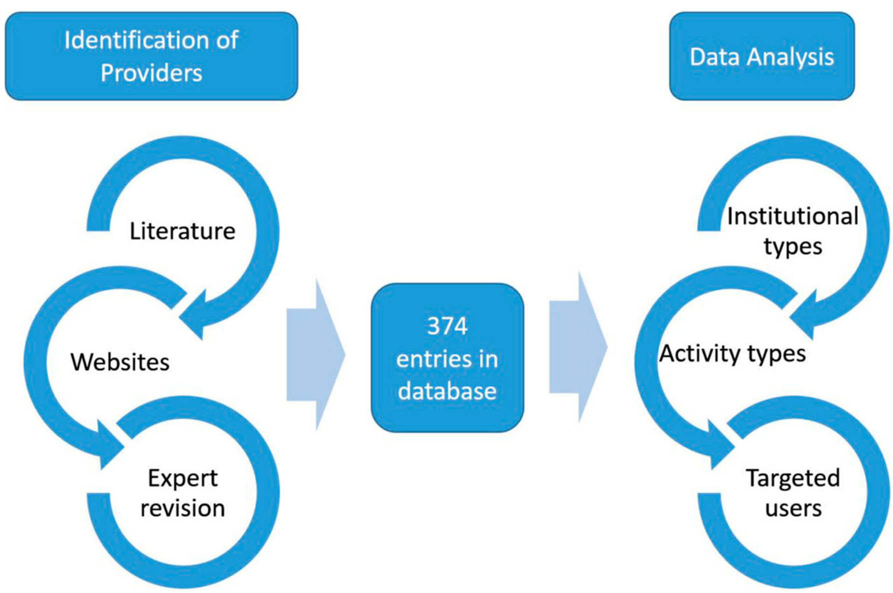

Figure 1. Approach to database development and analysis.

publication (2017b) on national ice-information services, Dawson et al.'s assessment (2017) of providers and users around the theme of polar mobilities, and a list of projects involving Arctic stakeholders by Knecht, Herber, and Stephen (2018).

To complement the literature review, we also examined polar NMHSs websites, UArctic member profiles (UArctic, 2018) on organizations involved in research, and information on the Climateurope website (Climateurope, 2018), to identify climate service providers. Furthermore, in order to locate emerging, and potentially unconventional, providers, such as start-ups and tailored services, we reviewed *The Arctic Inspiration Prize* finalists (The Arctic Inspiration Prize, 2018), checked start-ups participating in ESA's Start-up Space zone at the International Astronautical Congress (IAC) 2018 and searched for weather service and polar-prediction-oriented start-ups in key search engines DuckDuckGo and Google. This step in the scan process enabled us to identify providers not necessarily captured by the scientific literature or in technical reports due to their recent initiation. We compiled the information collected in form of a database of different polar WWIC providers and then circulated this preliminary database among a group of experts associated with the Year of Polar Prediction (YOPP) of the WMO in order to verify the entries and fill in possible geographical and organizational gaps in the database.

We then analysed the providers by reviewing their websites in order to draw additional information about their institutional background, activities and targeted users. The main criterion in this step was that the website needed to have sufficient information in English. In the process of provider identification and analysis we categorized the providers based on three main criteria:

(1) The type of provider organization (Cortekar, Lamich, & Tart, 2018);
(2) The type of provider based on their orientation toward WWIC information provision in polar context (following Vaughan & Dessai, 2014) and;
(3) The types of users that the provider organization targets in polar context.

First, the organizational type of provider is mainly determined by the institutional structure it sits in, including: NMHSs, public polar service centers, academic institutions, non-profit-organizations, professional bodies, public administration and policy, large companies, small and medium-sized enterprises, and start-ups (adapted from Cortekar et al., 2018). To clarify, public polar service centers refer to public organizations that provide Polar specific and WWIC-related information. Professional bodies are mainly collaborative organizations aimed at coordinating and managing different tasks related to polar research, environmental monitoring or international governance. Providers in public administration and policy include authorities dealing with polar governance and United Nations specialized organizations, such as the WMO.

Second, in terms of the activity types specifically oriented towards WWIC provision, we follow the terminology of Vaughan and Dessai (2014) on the arrangement of climate services. We distinguish the following categories: coordinating bodies, monitoring groups, service providers, services, and users. Coordinating bodies aim to support the development of WWIC services and work in the user-provider interface to increase the uptake of WWIC information. Monitoring groups are typically cross-sectoral groups that discuss polar issues. Service providers supply WWIC information and services and may contribute to different stages of service provision process (observations, information systems, forecasts, tailoring of services, etc.) while services may be websites, portals, platforms, tools, bulletins or products involving direct provision of WWIC information. In summary, service providers play a more substantial role in primary data acquisition than services that are by default closer to the end-user. Users may also disseminate information or participate in the development of WWIC services.

Third, we categorized providers based on their targeted users. Here, we identified different characteristics, such as the target region for the information provision (Arctic (including the Baltic Sea area), Antarctic, or both Polar Regions), spatial foci of the user (i.e. local, regional, national, continental, global) and the sectors they were servicing. The sectoral categories were formulated inductively by first identifying specific sectors (e.g. shipping) and then formulating umbrella categories (e.g. commercial activities). We also identified the countries where the providers are located.

The resulting database provides a unique inventory of organizations involved in WWIC information provision (Haavisto et al., 2019), but it is not, by any means, exhaustive. It is intended as an overview of the main WWIC sources utilized to support activities in Polar Regions. The main limitations of our methodology are the messiness of the approach, which refers to the process of identifying informal and private sector organizations, and the difficulties associated with the categorization of the providers. For example, when categorizing organizations and services, some might fit into more than one category. We assigned categories through the polar and WWIC lenses, and our intention was to designate a provider to just one main category based on their identified primary purpose, even though the organization could have multiple activities related to WWIC information provision. It is also noteworthy that our database contains, aside from organizations, services (e.g. websites and projects that target polar users) that may be maintained by provider organizations. Therefore, there is some spatial bias, for example, when looking at the whole database and the geographic locations of the providers. Finally, we also have not fully covered indigenous knowledge as a source of WWIC information. These aspects should be taken into account when interpreting the results.

Results – overview of WWIC information providers

The final database consists of 374 WWIC providers and services. They are based in 33 different countries (see Figure 2) – 24% from the USA, 9% from Norway and 9% from Canada. 33 providers are exclusively focused on the Antarctic, 185 on the Arctic (including the Baltic region) and 145 on both Polar Regions. Additionally, we identified 11 providers of which we are not certain if they already serve polar users, but they have the potential to do so. In 21 cases, we could not identify the country because a national affiliation was not clear, or the provider represented a partnership or operated via an online platform rather than a fixed organization. From the total 374 entries, 30% are academic institutions and 21% professional bodies (Figure 3). Providers with a commercial focus account for 14% of the providers identified%. NMHSs and non-profit organizations each represent 9% of the total share of providers, while public polar service centers and public administration and policy account for 8% respectively. In terms of activity types, 39% of the providers were identified as service providers, 31% as services, 17% coordinating bodies, 10% users and 3% monitoring groups (Figure 4). Activity types may also operate at different spatial scales, the largest category being global (see Haavisto et al., 2019).

We also examined how different institutional types of service providers are involved in different activities (Figure 5). Academic institutions as the biggest institutional group are

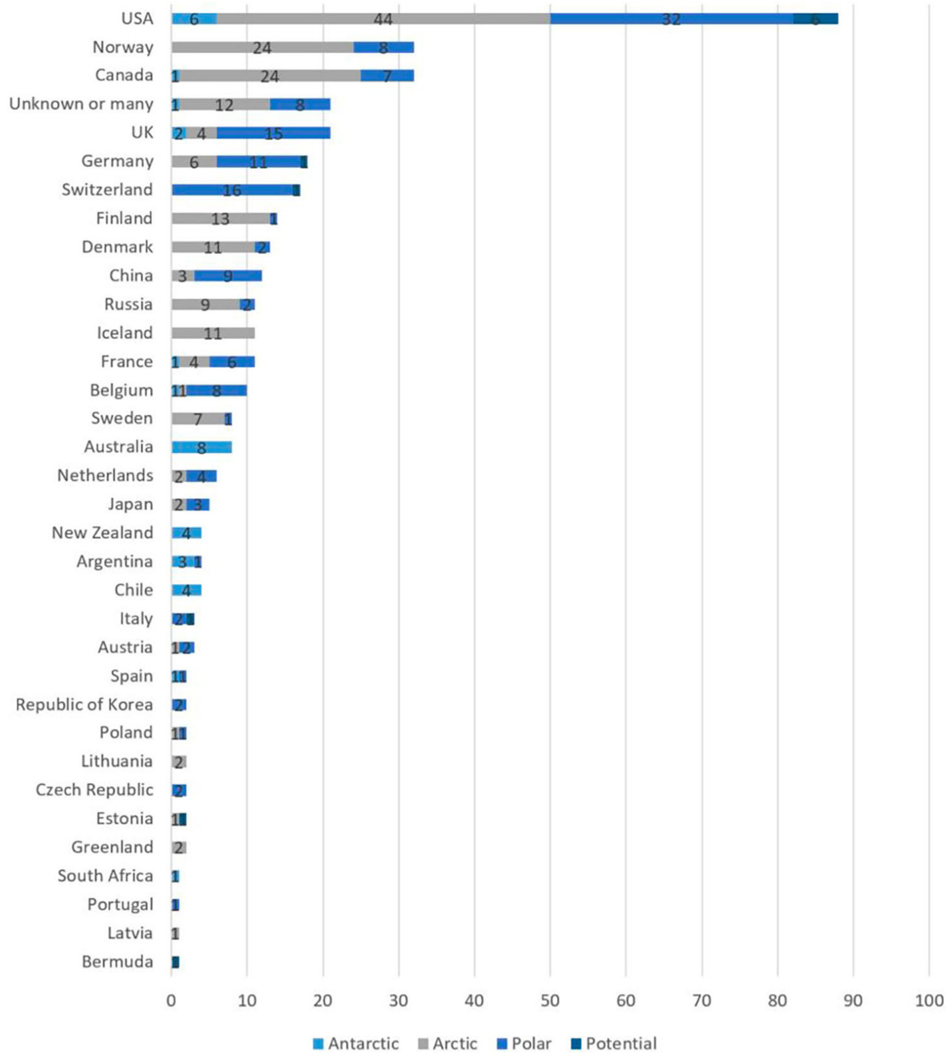

Figure 2. Providers in different countries and their Antarctic, Arctic and Polar focus, as well as the potential to serve polar users.

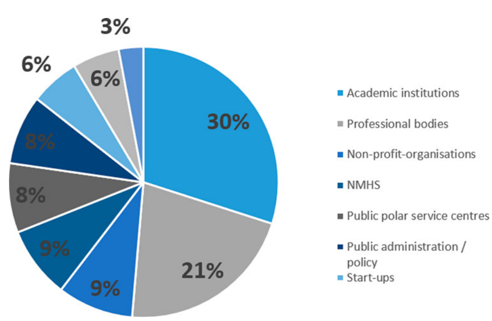

Figure 3. Share of institutional types providing WWIC services.

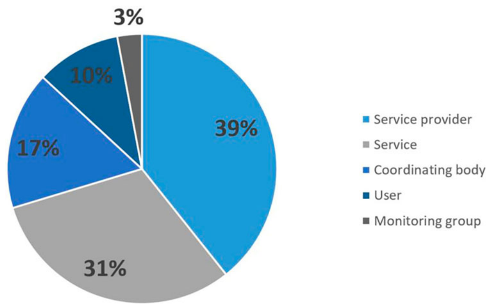

Figure 4. Share of activities undertaken by WWIC providers.

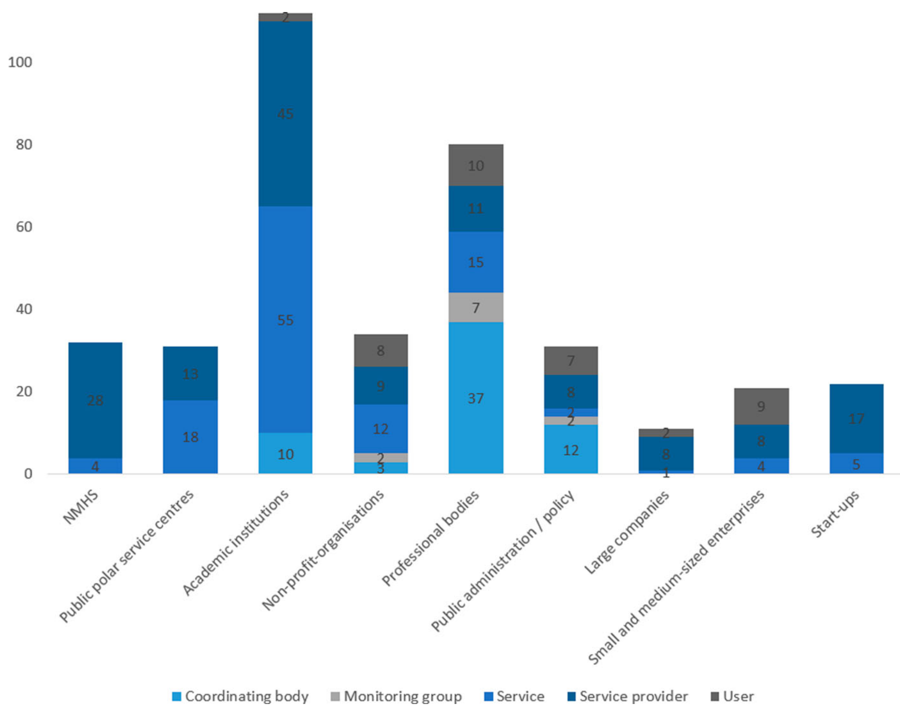

Figure 5. Number of activity types according to institutional types of WWIC providers.

mostly involved in delivering specific services (platforms etc.) and as service providers. NMHSs are mostly marked as services providers because they provide a wide range of services.

Providers are targeting users in a variety of sectors. Figure 6 shows that 44% are targeting science and 26% commercial activities, including mainly marine activities such as shipping, fisheries, extractive industries, tourism and recreation. The society-at-large sector accounts for 16% and comprises multiple uses that are difficult to assign to a single sector (e.g. public weather services). Policy and decision-making, including environmental protection and the science-policy interface, is targeted by 9% of the providers. Education is the main reported by 3% of the providers. Lastly, local communities are specifically mentioned only by 2% of the providers, although there are various public services in the society-at-large sector that would also be servicing communities. It is hard to draw straightforward conclusions about the targeted users as in many cases the providers' websites do not explicitly

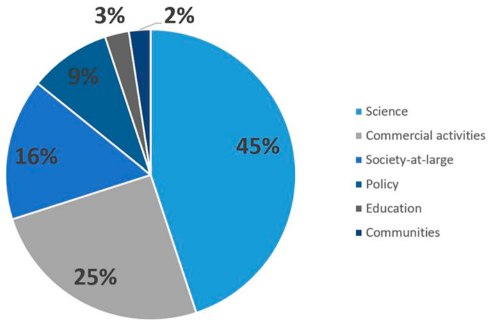

Figure 6. Sectoral focus of the users targeted by WWIC providers.

state who they are targeting. Even when they are clearly stated, providers often list a range of users, which makes it difficult to assign them to a single sector. However, it is clear that marine activities are by far the main focus of WWIC information in the Polar Regions, accounting for about one-third of the database entries.

Discussion

Provider-scape and global societal drivers

The database analysis presented in this paper is a snapshot of providers and is the first known attempt to specifically characterize the polar WWIC provider-scape. It shares some similarities with the mapping exercise by the Arctic Data Committee (2018), which focuses mainly on the Arctic and on a wider range of data sources. It is difficult to interpret how societal drivers may have affected WWIC information provision in the Polar Regions, but some observations can be made. Overall, the societal drivers we discuss below are more prominent in the Arctic, largely because of the presence of a human population and growing economic activities. In the Antarctic, the developments identified generally relate to technological advancements and to some extent to growing demand from expanding tourism and fishing activities.

Polar Regions at the forefront of climate change

Even though climate change has placed the Polar Regions into the limelight and increased the awareness of the role that WWIC information plays in risk management and adaptation, the most significant provider-user interactions appear to happen within the scientific community, as research organizations dominate the provider-scape and as science is identified as the largest user. This is in line with efforts by the WMO and its World Weather Research Program (WWRP) to increase observational capacity in the Polar Regions. Such efforts will serve scientists and NMHSs in the first place, while benefits to communities will only be realized when model results improve or when the data are tailored towards more user-specific services.

Neoliberalism and privatization of WWIC information

To provide a WWIC service, an organization needs to have infrastructure (observations, information, forecasting and warning systems) in place or available to them. These 'upstream arms' of NMHS consist of everything associated with raw data generation which all the services are built on, while the 'downstream arms' are providing more specialized services (Pettifer, 2015). In other words, the 'upstream arms' are necessary for any kind of WWIC service to be developed, while the 'downstream arms' are the elements required to refine the data into a user-friendly format or product. The end result might be a public weather, aviation, marine, agricultural or climate service. Neoliberalism and the privatization of public services may be a global phenomenon, but in the polar WWIC context, private organizations account for a rather small share of the providers (14%). Instead, publicly funded research organizations, NMHSs and public polar service centers account for almost half. The snapshot of the current provider-scape emphasises that, compared with the previous studies (e.g. Duske, 2016; EC-PHORS, 2015), there are more private WWIC providers than previously identified. The private organizations included in the database are mainly servicing commercial users, with an emphasis on tailored or sector-specific weather services, marine services and climate services, but they are not involved in the 'upstream arms' of observing data. In most cases, private organizations do not actually target the Polar Regions alone, but rather aim to fulfill WWIC information needs that are global. Overall, polar WWIC information start-ups are still very rare, even though there are many national and international accelerator programs focused on tackling climate issues (e.g. Climate-KIC in Europe).

Technological advancements in WWIC information provision

Technological developments have dramatically altered the ways in which we collect, store and share WWIC data. They have also improved our capacities to analyse data and to run complex models. Overall, technological advancements seem to be more focused on the production process of WWIC information rather than the uptake of information. Research in the Polar Regions has an important role, especially with regard to the governance of the regions. For example, wildlife conservation and biodiversity are dependent on research and environmental monitoring, especially in the presence of climate change and expanding human activities. The provision of WWIC services for the Polar Regions potentially benefits from research efforts, which is why there has been an emphasis on the development of transparency and accessibility with regard to polar WWIC data. Many services included in our database focus on information systems that enable the sharing of different WWIC datasets or delivering marine services. Even though current technology enables the development and delivery of many applications, there is still room for improvement with regard to technological capabilities to provide targeted information at local community levels and to support different user needs. Unfortunately, these improvements are currently hindered in many communities by, for example, connection and bandwidth limitations.

Remote communities are mainly serviced by non-governmental organizations and research organizations. However, communities, especially urban settlements, can also benefit from privately and publicly provided services that are targeted more broadly to society-at-large, if the technological requirements of remote locations and other aspects of community needs are taken into consideration. While technological advancements are likely to take place and increase the possibilities of WWIC information uptake in sectors that have not been able to utilize such information before, considerable work remains to be done in the actual service development and in operationalizing coproduction (Bruno Soares, Alexander, & Dessai, 2018).

Unintended consequences

Better WWIC services in the Polar Regions are important to enable safer operations, and may be required for certain economic activities to be pursued at all, but improved services can also create an illusion of safety, thus inviting risky behaviors. Moreover, such services may increase opportunities for environmentally unsustainable economic activities, such as intensive fisheries and small-vessel operations, if these activities are not governed properly. This is a real concern in both Polar Regions, where cruise tourism and yachting are already increasing due to increased interest in polar tourism in general, and in adventure and wildlife tourism in particular (Dawson, Pizzolato, Howel, Copland, & Johnston, 2018; Johnston, Dawson, De Souza, & Stewart, 2017; Lamers, Stel, & Amelung, 2007; Liggett, McIntosh, Thompson, Gilbert, & Storey, 2011). These activities require greater preparedness and operational experience by the individuals taking part in them and more capabilities for search and rescue operations.

Economic development in the Arctic has long focused on marine resource extraction, especially fisheries, and mineral and hydrocarbon exploitation (Arctic Council, 2009). In the Antarctic, resource extraction is currently limited to fishing, particularly for toothfish and krill (Ainley & Pauly, 2014). In Arctic marine governance, WWIC information may create legitimacy and build trust, but may also lead to conflicts and controversy by empowering some actors more than others (Lamers, Pristupa, Amelung, & Knol, 2016). If improved WWIC services contribute to more extensive resource extraction in the Polar Regions, this would counter many global efforts to transition to a sustainable low-carbon future as envisioned by, e.g. the Paris Agreement (United Nations, 2015a) or the 2030 Agenda for Sustainable Development (United Nations, 2015b). It would also influence global and regional efforts to protect biodiversity (e.g. CITES and PAME).

The illusion of safety in Polar Regions is currently neither well understood nor investigated. The issue has only been touched upon in a polar WWIC services context by Lamers, Knol, and Ljubicic (2017) and Dawson et al. (2017), but not as a main research topic. Since our results on the targeted users of the WWIC providers show that almost half of the providers (45%) are aimed at commercial activities (e.g. shipping, tourism, resource extraction), the illusion of safety and the possible counter-effects of improved WWIC services constitute important challenges to be addressed by science and policy in the future.

Indigenous and local knowledge in WWIC information provision

Our analysis has focused on WWIC providers that offer formal services defined by the presence of an overt mandate (i.e. legislated, officially sanctioned, institutionalized or commercialized), an organized structure and source of resources, and technologically-enabled means of disseminating science-based information to a targeted user base. While these formal services are important sources for WWIC information, we acknowledge that there are other ways of sharing relevant information on weather, water, and ice conditions that are generally not accessible through publications, data portals, or formalized WWIC institutions. Notably, 'indigenous and local knowledge is accrued through long-term observation and lived experience, in other words by 'doing'. This knowledge is typically held and shared by those with considerable experience with a given occupation, practice, lifestyle or activity' (Dawson et al., 2017, p. 13).

Over the past two decades, indigenous knowledge of safe ice and weather conditions has received considerable academic attention (e.g. Alessa et al., 2016; Aporta, 2002; Baztan, Cordier, Huctin, Zhu, & Vanderlinden, 2017; Durkalec, Furgal, Skinner, & Sheldon, 2014; Gearheard et al., 2006; 2013; George et al., 2004; Hansen, Brinkman, Leonawicz, Chapin III, & Kofinas, 2013; Krupnik, Aporta, Gearheard, Laidler, & Kielsen-Holm, 2010; Laidler et al., 2009; 2011; Rees, Stammler, Danks, & Vitebsky, 2008). Such knowledge is very rich and specific to a given location, time of year, and activity, in relation to seasonal travel, leisure, commercial ventures, or subsistence harvesting. It is often accumulated through many generations of practice and knowledge sharing, and is predominantly shared orally (i.e. in person, over community radio, short-wave radio or satellite phones). Such in-depth local knowledge, however, is not restricted to members of indigenous societies but instead 'is also prevalent among individuals engaging regularly in activities sensitive to WWIC conditions, such as ice road haulers, base managers, deep field scientists, tourism itinerary planners, expedition guides and ship captains' (Dawson et al., 2017, p. 13).

Because of rapidly changing environmental conditions and, in some cases, reduced confidence or experience with traditional navigational skills or safety indicators, some communities have begun to initiate their own community-based monitoring programs (Alessa et al., 2016; Druckenmiller et al., 2009; Eicken et al., 2014; Gearheard, Pocernich, Stewart, Sanguya, & Huntington, 2010; Johnson et al., 2015; Kouril, Furgal, & Whillans, 2016; Mahoney, Gearheard, Oshima, & Qillaq, 2009). Since our results show that only few WWIC providers target local users (n = 9; see Haavisto et al., 2019), the emergence of community-based monitoring enables the tracking of WWIC conditions in locations and at scales that are most relevant to local decision-making (Dawson et al., 2017). Since WWIC providers are not restricted to those housed within government agencies, commercial ventures or academic institutions, it is important to highlight that non-profit or community-based monitoring networks and organizations also develop and deliver important information to those affected by WWIC conditions in the Polar Regions (Johnson et al., 2015; Kouril et al., 2016).

However, the contributions of non-profit and community-based networks to WWIC service provision are not well understood and are underrepresented in the literature and other online search engines because (i) they operate on more local and interpersonal levels, and (ii) their ways of sharing information may not be publicly available. While these informal or emerging networks are critical in terms of providing local information and warnings, they cannot be adequately captured in a database analysis. A full review of these local initiatives would require a different methodology and is beyond the scope of this paper. However, a few key examples of community-based monitoring activities established in the Arctic Region include the Sea Ice for Walrus Outlook (Arctic Portal, 2017), the Local Environmental Observer Network (LEO, 2017) and the Alaska Arctic Observatory & Knowledge Hub in Alaska, and the Arctic Eider Society's Community-Driven Research Network (AES, 2017), SmartICE (2017) and the Clyde River Weather Network (CRWN, 2017; Pulsifer et al., 2012) in Canada.

Conclusions

While an exhaustive review of WWIC providers and services in Polar Regions is beyond the scope of this article, we have presented and discussed the provider-scape for polar WWIC information provision. First, we identified information providers based on existing literature and targeted searches. Second, we analysed provider websites based on three main criteria:

type of organization, type of activity towards WWIC information provision, and users they are aiming to service.

We found that various institutional types are involved in WWIC information provision in the Polar Regions. Around half of the providers are academic institutions and professional bodies. The majority of the identified organizations are either service providers or services. Science is the biggest targeted user group, with commercial activities coming in second. Services targeted at local level are more rare but seem to be emerging.

The need for social-science research regarding the development of climate services has been highlighted by many scholars (e.g. Vaughan & Dessai, 2014). Social sciences can provide important insights on information needs, on issues relating to the uptake of information or on the societal implications of technology development. With an increase in activities in the Polar Regions, attention should be paid to the delivery of WWIC information to those who need it. This is particularly pertinent in a future that is likely to be characterized by an increase in extreme weather events in the Polar Regions due to climate change and in a system that is increasingly reliant on WWIC service provision by private organizations. Considering that these private organizations are inherently nested in a neoliberal global system and are pursuing profits with their operations, we will have to consider whether vulnerable users will be able to pay for WWIC information services in the future.

Notes

1. Please be aware that not all relevant expertise can be captured in this rapidly changing space in the academic literature. To keep track of relevant polar data workshops and working groups see: https://arcticdc.org/ (accessed 14.10.2019)
2. PPP-SERA, a task team of the Polar Prediction Project, addresses social science and economics aspects of polar predictions. More info available on the website: https://www.polarprediction.net/about/organization/yopp-task-teams/#c18740 (accessed 14/10/2019).

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